The evolving nature of China's regional innovation systems: insights from an exploration-exploitation approach

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Abstract: The regional innovation systems (RISs) approach has become influential in analysis of innovation processes and the development of public policy. Much of the contemporary RIS literature, however, has adopted a structural, functional, effectiveness or triple helix analytical approach. This study enriches our understanding of RISs in East Asia by considering an alternative novel perspective at the RIS level: an exploration-exploitation approach. Though often used at the firm-level, we argue it may also provide an alternative lens through which to understand the evolution of China's RISs. To this end we construct a provincial entropy index and use K-means to categorize provinces into explorative, exploitative and balanced RISs and their evolution between 1986 and 2011. Our findings contribute to the literature on China's RISs by illustrating in greater detail the persistence of certain RISs across many of China's provinces, as well as the dramatic step changes towards exploitative systems in others.

Keywords: Regional innovation systems, analytical approach, exploration-exploitation, China

1. Introduction

During the 1990s the systems of innovation approach largely replaced the traditionally linear or Schumpeterian view of firms innovating in isolation [1]. The systems approach argues innovation should be considered as an evolutionary, non-linear and interactive process. It requires intensive communication and cooperation between different actors both within and between companies, as well as other institutions (such as universities, suppliers, customers, competitors, research labs, educational institutions, financing agencies, governments, and other partners) [2, 3]. More recently, the concept of innovation systems has been applied at the national level [4] and also to technological [5], sectoral [6] and regional dimensions [7]. Different dimensions of innovation systems may complement each other and together provide insights into better understanding the nature of innovation. All types of innovation systems consist of interaction among the different participating elements, which may eventually involve the generation, diffusion, and application of knowledge [8].

Scholars studying systems of innovation have forcefully argued that the regional nature of such systems is of considerable importance. Regions, for instance, generally differ in terms of their patterns of industrial specialization and other elements of their innovation systems, leading to differing innovation performances [9]. This is particularly so in the case of China, a large country with considerable regional disparity. Moreover, knowledge spillovers, which play crucial roles in the innovation process, are often also spatially bounded [10]. As such, research on regional innovation systems (RISs) has become increasingly popular in the analysis of innovation processes and regional public policy [1, 11].

The RIS approach has been widely interpreted to explain some influential and successful high-tech industrial clusters (i.e. Silicon Valley and Route 128 in the United States). By identifying key actors, institutions, infrastructure and their interactions within a well-performing cluster or region, RIS scholars have attempted to explain why innovation may become concentrated in certain regions. It has also identified what types of actors, institutions, and linkages are at play [12-14]. Accordingly, regional public policy has been crafted based on such analyses, leading to focuses on high-tech or knowledge-based industries, increasing research excellence, attracting globally competitive firms, and stimulating university-based spin-offs [15-18]. Recently, scholars have noted that innovation in a global learning economy is critical for all types of regions. This includes not only high-tech clusters in advanced economies but also mid- and low-tech industries in developing countries [1]. Thus, regional innovation policy has been developed through analysis of specific regions.

This being said, some have noted the inconsistent policy prescriptions of much contemporary RIS literature, as well as the comparatively static methodological approaches that have been used at times [8, 16, 19-22]. A broad range of the RIS literature adopts approaches used in studies of national innovation systems (NIS). This includes: the structural, effectiveness, functional and triple helix approaches. These commonly used approaches are static in nature, involving snapshots of a focal innovation system to describe structures, functions and interactions between key actors, including universities, industries and governments [23]. Thus far, many scholars have therefore failed to provide a holistic approach to empirically delineate a RIS, particularly one incorporating longitudinal and dynamic analyses. Furthermore, inconsistent policy recommendations have been reached [24]. Additionally, continuing globalization and the rapid rise and fall of regional industrial clusters in developed and developing economies alike adds considerable complexity to the spatial dynamism of innovation processes [25, 26]. It thus becomes increasingly relevant for innovation scholars and policy-makers to understand how innovative activity is organized regionally and how RISs evolve during the course of development. Further research using alternative methodological approaches for understanding RISs could therefore be beneficial, particularly if these approaches can capture the evolutionary dynamism of RISs and provide insights into policy-making.

Our objective here is twofold. First, we introduce and discuss a novel analytical approach for the study of RISs which we borrow from the exploration-exploitation framework, often used for firm-level analysis. Using this approach we categorize RISs into a limited number of classes and develop a patent-based measure of innovative activity. This gives us a workable method for undertaking longitudinal research on China’s RISs. We also consider extant research on China’s RISs and consider how our novel approach may contribute to further understanding it. Second, we undertake a preliminary application of this approach to Chinese provinces as the RIS unit of analysis. China has increasingly gained ground with respect to RIS development during the past three decades. Its emergence as an innovative economy and society, moreover, is crucial to its longer term growth. Indeed, so central has innovation become to China, developing better innovation systems is increasingly considered the key to escaping a potential middle income trap.

This paper is organized as follows. The second section discusses the primary analytical approaches in contemporary RIS (or NIS) studies and summarizes their application to the Chinese case. The third section discusses the novel RIS exploration-exploitation framework and the fourth section applies it to China’s RISs. The conclusion argues that the qualitative evolution of patenting in Chinese provinces is striking though often overlooked aspect of Chinese RIS development. We show not only that provincial patent volumes increased dramatically during reform but also that their variety across technological classes has evolved significantly. This has led to the emergence of some regions with considerable depth and breadth in patenting activity, regions that may be considered as exploratory RISs.

2. Dominant analytical approaches in the study of RISs

Careful scrutiny of the current literature stream reveals that at least four separate though at times complementary approaches have been developed for the understanding of national and also RISs (see Table 1).

2.1.1. The structural approach.

The structural approach is among the most popular methods for describing and identifying structural elements within innovation systems. These elements have consequently been used to interpret the systems' relative innovative performance [27, 28]. Since Freeman's (1987) first articulation and use of the term 'national innovation system' (NIS), this approach has dominated the analytical toolbox. Likewise, with regard to RISs, the structural approach generally leads to detailed analysis of the main elements characterizing an RIS. It thus explores elements that characterize the main institutional actors, firms and other institutional actors that comprise the RIS. Following this approach, scholars usually stress the primary innovative profile of a region by characterizing innovation activities using indicators such as education, regional R&D investments, existing technological base and technological outputs (e.g., patents and new product sales) [22, 29]. As a result, regional differences in terms of innovation activities and competitiveness have been attributed to elements that characterize RISs. Guided by this approach, local governmental authorities typically focus on the creation of primary elements to improve the RIS. For instance, regional governments may look to create centers of excellence, attract global companies and attract important innovation intermediaries.

2.1.2. The functional approach.

The functional approach was introduced in the 2000s though its roots can be traced back to Edquist's [3] discussion of the R&D function in national innovation systems. Edquist states that different organizations or actors (e.g., research institutions, company R&D units, or universities) in various national systems of innovation can perform the R&D function. This approach has since been widely developed by scholars [24, 30-32]. Generally speaking, the functional approach identifies important functions or activities that play key roles in the processes of innovation production, dissemination, and application [30]. These functions are generally created to support the overall goals of national (or regional) innovation systems, such as technical advances, economic growth, job creation and competitiveness [33]. Different scholars present different function portfolios. In many cases, education and training, knowledge development, intellectual property rights protection, resource mobilization, linkage and formation of markets (including technology markets) are often considered in scholarly research [e.g. 31].

The functional approach has attracted a lot attention since its inception, as it considers numerous elements and heterogeneous structures of similar functions in various innovation systems [32]. This consideration may in turn provide a limited number of aggregate variables to explain the differences between different national innovation systems [34]. Under this approach, regional governments' policies hence shift their focus from cultivating specific elements to making RISs function well.

2.1.3. The effectiveness approach.

This performance-based approach avoids evaluating the complex nature of innovation systems, in which most actors and elements are socially embedded and the mechanisms used to coordinate them are not identical to market mechanisms [35]. Under the effectiveness approach, inputs and outputs of the innovation system are roughly defined (in a similar way to some classic economic analyses, e.g., Leontief's input-output tables)[36]. Inputs may include, for example, R&D investments, the number of scientists and engineers and the number of universities and research institutes [37]. Patents, sales, employment, and economic growth rates are often defined as innovation system outputs [38]. Efficiency assessment methods, such as data envelopment analysis (DEA) [39] are widely used. The variation in performance provides potential comparisons of the effectiveness of different systems. Researchers label this type of research, which aims to assess effectiveness, set benchmarks, and identify factors that foster or hamper innovation systems' development and operation, as an effective method or system failure analysis [40]. This analytical method presents greater potential for plotting system failures when public supports are required [38, 41].

2.1.4. The triple helix approach.

The triple helix approach initiated by Leydesdorff and Etzkowtz [42] seeks to understand the dynamic interactions between university, industry and government, which play key roles in innovation systems for facilitating entrepreneurship, innovation and economic growth [15]. This new approach focuses on three important actors rather than the numerous actors that perform complex functions in innovation systems and has shed new light on interactions among these three actors [43, 44]. A crucial assumption is that compared with other actors, the contribution of universities to industrial innovation has become increasingly important. In the triple helix, interactions between university, industry, and government therefore deliver optimal conditions for facilitating innovation [45]. To date, the triple helix approach has been used as a normative approach for understanding interactions between key innovation system actors. In practice, many governments in developed and developing countries have adopted this approach in building national or RISs [15].

2.2 Understanding China's RIS

There is great interest in China's national innovation system (NIS), and consequently also her RISs[46-50]. As Li points out, dual systems of innovation co-exist in China, in part owing to its transitional nature and the rapid development stages it is passing through [48]. Considering China as a single NIS, therefore, becomes problematic, as the diversity and richness of China's different regions may be lost when considering the country as a whole. Its NIS is thus too large and sophisticated to be investigated only at the national level [46]. Alternatives, such as exploring Chinese RISs by provincial breakdown or region, have now become more common. Most of these approaches, moreover, have adopted one of the aforementioned four RIS perspectives.

Recent research on China's RISs has been particularly interested not only in explaining the very rapid development of patenting activity but also the growing regional disparities [48, 50, 51]. There has thus been a considerable focus on the overall volumes of patenting activity and types of forces motivating regional disparities. This is an interesting problem, as Li points out [48, 49], because the growing regional disparities cannot entirely be explained by the resources dedicated to such activities. Li (2009)[48], for example, uses a stochastic frontier model to explain the increasing regional disparity in innovation performance in China's RISs. The question Li raises is: Why are there growing disparities in innovation outputs between provinces when the comparative resources dedicated towards innovative activities have remained roughly the same? Li finds the answer lies in the efficiency with which innovation is undertaken, and specifically that as innovation shifts to firms (as opposed to university and research institutes), variations in the efficiency of innovation between firms across regions explains part of the unequal spread in innovation activity. He also finds government support and the regional industry specific innovation environment are significant determinants of innovation efficiency [48].

In later research Li (2012)[49] returns to the question of disparities in regional patenting activity in China, particularly in the post 2001 period, which saw a dramatic upturn. Li notes that conventional explanations had stressed the growth in R&D investment, FDI, better legal systems and ownership reforms all as important stimulus to the rapid growth in regional patenting activity. Li argues that China's entry to the World Trade Organization and strengthening of its IPR regimes provide one potentially convenient set of arguments for explaining the patenting upturn. He also argues, however, that these are not adequate explanations, as they do not explain the regional disparities in patenting. An improvement in IPR protection would favour patenting activity in all provinces, not just some. Li (2012)[49] therefore provides an institutional explanation for the growth of patenting activities in China, specifically suggesting that patent subsidy programs aimed at encouraging patenting through deductions and application fee reimbursements have acted as a vital stimulus. Based on province-level data across different applicants the empirical evidence from his regression analysis supports this argument, showing that the grant ratio of applications has increased since the implementation of patent subsidy programs: 'Patent subsidy programs initiated by local governments have unambiguously given a great impetus to domestic patenting. They have also proved crucial in widening the patenting disparity across regions' (Li, [49]: 240). It is interesting to note, moreover, that these programs did not discriminate according to technology classes and gave rise to a pervasive rise in patenting across technology classes. In 1999, for example, Shanghai launched a special fund to subsidize the fees incurred during patent applications for individuals and organizations registered in Shanghai. Shortly after, in 2000, five other provinces and cities (including Guangdong, Beijing, Tianjin, Jiangsu and Chongqing) launched similar programs (by 2007, 29 out of 30 provinces in mainland China had launched a patent subsidy program). It is notable today, as our later results show, that six of the seven provinces we identify as exploratory in 2011 all came from this pioneering group.

As well as considerable amounts of research using structural approaches, those using functional, effectiveness and triple helix approaches to study China's RISs are common. Chen and Guan [46], for example, use partial least squares to incorporate various functional constructs that they argue together determine China's innovation system performance. Using a province–year panel dataset over the 10th five-year plan period they look at the effectiveness of the functional constructs influencing China's regional innovation processes. Their results show that China's RISs perform well in terms of most functional constructs with the exception of innovation linkage and sophistication [46]. Like Li [48, 49], they also find that RIS innovation performance in China is not only determined by total resources dedicated to R&D, but also innovation efficiency determined by institutions and framework conditions.

In terms of an effectiveness approach, a number of studies have looked at Chinese innovation outputs and resulting outputs, considering the effectiveness of her RISs, including performance assessment and the evaluation of input-output efficiency. Sun and Liu [50], for example, use a regional specialization coefficient (RSC) method to analyze the structural transformation of China's NIS from the perspective of eight large economic regions between 1999 and 2006. Like others (i.e. Li [48]), they find a transition from a government to enterprise led model is important. Finally, significant volumes of literature on China's local regional innovation systems have used approaches which focus on the triple helix relationship between government, business and universities and research institutions. For example, significant research interest has been shown in science parks and business incubators across China's regions [52]. This research typically has considered the interactions between the three core elements of the triple helix.

In general, analysis of China's RIS has been driven by the structural, functional, effectiveness and triple helix approaches. These lenses have led to a focus on regional disparities in patenting activity (with a focus on patenting volumes) and have placed emphasis on, among other things, the growing disparities in innovation efficiency as R&D activities have shifted to firms. They have also emphasized the role of institutions and province level policy, particularly regional schemes lowering costs of patent applications.

2.3. Advantages and disadvantages of common RIS approaches: why use an alternative framework?

A weakness of the aforementioned approaches (and their application to the Chinese case) is that they tend to shed comparatively little light on dynamic aspects of RIS evolution. At times, moreover, their implications for policy-making are not clear (Table 1). For the dominant structural approach, for example, it is hard to delineate all of the elements a complete system. It may also be difficult to export it to another system. Even within the same system, moreover, elements and linkages are constantly evolving over time. It is thus challenging to capture those components that are important at one time and connect them to general policy-making processes. With respect to policy-making, different RISs may have different characteristics. A one-size-fits-all policy drawn from a typical well-functioning innovation system, therefore, might well be inappropriate. Cultivating important elements and linkages from a benchmark system to a focal system might also be less effective [1]. For the functional approach, a similar problem occurs when different functions play unequal roles in different systems or within the same system at different times. More importantly, a function that is carried out by a particular set of actors in specific forms may be carried out by another set of actors in a similar system at a different time or in other systems [31]. Thus, empirical results from functional analyses may have comparatively little value for policy-makers.

The input-output analysis of the effectiveness approach focuses on the flows of goods and services among actors in a RIS at a particular point in time [37]. This approach has thus neglected interactive relationships among system elements (i.e., the system is comparatively static). Owing to this weakness, it is hard for policymakers to draw implications without understanding the internal interaction processes. The triple helix approach pays substantial attention to the role of universities in innovation systems. While the role of academia in high-tech industries and in regional development is undoubtedly important, it clearly does not represent the entirety of the economy, particularly in emerging markets, where industries generally draw from more mature technologies, rather than advanced and new technologies [15, 53, 54].

The four approaches discussed have enriched our understanding of regional innovation, including that of China's RISs, as well as providing useful implications for regional innovation policy-making. Here, however, we explore an alternative approach for RIS research, one that may also potentially address some of the weaknesses we have identified (see Table 1 for a summary).

Table 1: Advantages and disadvantages of four common approaches for analysing innovation systems

Approach	Brief description	Advantages	Drawbacks	Key policy instruments
Structural approach	Identifies key structural elements in the systems (e.g., well-functioning systems)	Visible, straightforward, with potentially useful implications for policy-making	Impossible to identify all of the elements and difficulties in conducting comparative analyses	Reinforces important elements and strengthens linkages among them
Functional approach	Simplifies considerably the number of elements to limited number of specific functions (i.e., activities) in a system	Reduces the complexity of systems and pays attention to several functions instead of the myriad elements	Hard to compare functions in different systems and within a system at different periods; also difficult to link functions to specific supporting elements	Instead of cultivating specific structural elements, more attention should be paid to specific functions related to knowledge generation, diffusion and use
Effectiveness approach	Links system inputs to their corresponding performance outputs to evaluate system efficiency and effectiveness	Avoids the hard work of unveiling the complex internal mechanisms in an innovation system	Hard to define innovation system inputs and outputs and to compare systems at different development levels	Improves innovation system effectiveness by optimizing inputs and improving system performance
Triple helix approach	Interactions between university, industry and government are key for an innovation system	Highlights the role of key actors (e.g., the university) for high-tech and emerging technologies or industries	Less applicable in mid- and low-high technologies or less advanced regions	Emphasizes universities' role in industrial innovations

3. An alternative approach for understanding China's RISs: an exploration-exploitation perspective

An exploration-exploitation approach used for understanding China's evolving RISs may provide an alternative and novel lens to understand RIS development. According to March [55], exploration is defined as 'search, variation, risk-taking, experimentation, play, flexibility, discovery, and innovation'. Exploitation, by contrast, is defined as 'refinement, choice, production, efficiency, selection, implementation and execution' (p.71). Since March's work, there has been a debate about how to exactly interpret these definitions. To date, a wide range of disciplines (e.g., organizational learning, technological innovation, organizational adaptation, strategic management, organization design, alliance, and technology transfer) has adopted the exploration-exploitation approach.

We take the position that both exploration and exploitation relate to forms of learning and innovation [56-58]. Whereas exploration includes activities for obtaining new knowledge, exploitation utilizes existing knowledge. Because organizations are usually confronted with limited resources, they are often subject to resource constraints, resulting in trade-off situations [59]. If organizations choose to invest greatly in exploration, they will have fewer resources for exploitation, and vice versa. This creates an inherent tension within organizations concerning whether to leverage existing technology for immediate results or alternatively look to explore new technologies for longer-term results [60]. Recent studies indicate that this tension might also result from other factors, such as organizational culture, norms, procedures and other path-dependent reasons. However, they also note that although there is a trade-off, organizations are still able to pursue both activities through solutions within organizational or macro-level mechanisms over time [61, 62].

3.1 Applications to regional innovation

Until now, the exploration-exploitation approach has been widely used in the technological innovation literature with a dominant focus on organization level analysis. Individual, team, inter-organizational, and sectoral levels are of increasing scholarly interest [59, 63-67]. The RIS literature, however, has largely overlooked the exploration-exploitation approach, despite possible linkages to it. Such connections exist as the exploration-exploitation approach is a way to distinguish between different innovative activities (or functions) by their specific purposes, namely for new knowledge creation or for existing knowledge use. Thus, this framework has some similarities to the functional RIS approach, which highlights different RIS functions. For instance, Bergek et al. [30] claim that knowledge creation is prevalent in exploration activities, while entrepreneurial experimentation, market formation, and resource mobilization are prevalent in exploitation activities in the exploration-exploitation approach. Autio [68] splits the RIS it into two subsystems: The knowledge creation and diffusion subsystem includes various institutions that engage in the creation and subsequent diffusion of knowledge and skills. The knowledge application and exploitation subsystem consists of companies, their clients, suppliers, competitors and their industrial collaboration partners [1]. Recently, two follow-up studies furthered this line of study. Liu et al. [69] and Wang et al. [70] both see two types of variety in Chinese RISs: the knowledge-generation type and the knowledge-application type. The former study argues that Taiwanese-based MNCs offshore R&D explorative networks tend to be located in Chinese knowledge-generation RISs. By contrast, exploitative networks tend to be concentrated in Chinese RISs that engage in knowledge application. Wang et al. [70] find that knowledge endowment (distinguished by knowledge generation and application types) moderates Chinese licensee firms' achievements in new product development from inward technology licensing in their regions where licensee firms operate.

Hence, although some scholars have realized and investigated the initial potential of adopting the exploration-exploitation approach, a specific study that addresses its application at the regional level is still lacking. Regional governments also face the same tension when investing their R&D resources. They can do so over a wide range of technological areas which may promise a region future prospects for new knowledge generation or, rather, they may narrowing their resources to limited technological fields to exploit their existing competences. From a long-term perspective, a balance between these two activities might facilitate avoidance of a ‘lock-in’ or ‘success trap’ [1, 16]. More importantly, when applying this approach to RISs, it may help deepen our understanding of the innovation processes taking place.

3.2 Features of explorative and exploitative RISs

Table 2 compares nine relevant features of explorative versus exploitative RISs. It should be noted that explorative and exploitative RISs are mutually related and build from one another over time. We note their features beneath.

- For explorative RISs, regional development strategy involves becoming one of the most competitive and innovative leading regions or, alternatively, a rapid follower of another frontier region with first-tier advantages. For exploitative RISs, by contrast, the main strategy is to import technology from leading regions and to imitate or be a slow follower.
- Explorative RIS competences are essentially built through breakthrough innovations. In most cases this entails technology-oriented activities and experimentation with novel combinations. In these RISs, tacit knowledge becomes crucial to sustain their competitive advantages. In exploitative RISs, incremental innovations or mature technology play a key role to maintain competence. Incremental product designs and processes that optimize oriented innovation activities are active in these regions. Experimentation in organizations becomes more visible rather than experimentation in novel

combinations with new technology. Due to the reduced variety in technological products and processes, codified knowledge becomes relatively important for RISs.

- Innovation sources in explorative RISs may be newly emerging ideas, knowledge and technology that are unfamiliar within that system. In contrast, innovation sources in exploitative RISs may be mature technologies, such as those imported from abroad or other regions. Through learning-by-doing, exploitative RISs accumulate knowledge and catch up technologically.
- The technology bases of explorative RISs and exploitative RISs are different. The former show moderate or lesser dependence on the existing technology base, while the latter demonstrate a higher dependence on its past technology. Regarding the scope of the technology base, the former are trying to widen their knowledge base to diversify the knowledge on hand. For the exploitative RISs, narrowing their technology base to benefit from technology specialization is the basis of their technology base.
- Concerning governance in explorative RISs, there are numerous new actors emerging, such as new entrants, spin-offs from universities, research institutes, and large companies. Many newcomers have also quickly disappeared. In this dynamic system, loose alliances and limited contract use might be appropriate, and due to the high-risk and uncertainty in innovation, there needs to be a relation-based trust among innovation partners. However, in exploitative RISs, due to the lack of dynamism, incumbents play the central role in using existing

mature technology for manufacturing, which is widely characterized by formal alliances, acquisitions, and formal market-based contracts (e.g., supplier-buyer contracts). Institution-based trust becomes popular in this system type.

- Linkages, an important RIS characteristic, become much denser and more open in explorative RISs. Because reciprocation is key during innovation, frequent interactions in explorative RISs are common. Frequency does not necessarily mean long durations are required, as this can prohibit the quick reconfiguration of ties, which enable the exploration of novel combinations. In exploitative RISs, by contrast, enduring long duration links are used to yield identification and reduce cognitive distance, thus strengthening capabilities in exploiting existing technology. Regarding the actors connecting to RIS networks, explorative RISs are often non-localized to garner a wide range of novel knowledge and skills for exploration activities, but localization is preferable for exploitative RISs.
- Regional norms, culture, and traditions play a key role in enabling innovation activities. With respect to explorative RISs, an open, collaborative, and risk-taking culture is generally required. However, the opposite culture might be beneficial for exploitative RISs.
- The R&D investments of governments present an important mechanism in regulating regional innovation activities. Thus, in explorative RISs, bottom-up, peer-reviewed and curiosity-based R&D allocation mechanisms are preferred for novel knowledge generation, diffusion, and use. By contrast, in exploitative RISs, top-down, mission-based, and performance-based (dependent on past

research) mechanisms are likely to be preferred.

- Finally, explorative RISs look more toward the regions' future and long-term innovation and economic outputs resulting from leading and advanced technology. In exploitative RISs, policymakers want to achieve immediate outputs by using existing technologies and capabilities.

Table 2: Characteristics of exploration and exploitation type RISs

	Explorative RIS	Exploitative RIS
Development strategy	Leading, rapid following	Imitation, slow following
Competence	Breakthrough innovations Technology-oriented Experimentation with novel combinations Tacit knowledge	Incremental innovations Product- and process-oriented Experimentation in organization Codified knowledge
Innovation source	Unfamiliar and emerging technology	Existing and familiar technology
Technology base	Moderate or less dependence—and wider	Highly related dependence—and narrower
Governance	New entrants, spin-offs, and start-ups Loose alliances Limited utilization of contracts Relation-based trust	Incumbents Formal alliances, acquisitions Formal market-based contracts Institution-based trust
Linkages	Dense, open networks Frequent interactions and short duration Delocalized	Non-dense, more exclusive networks Less frequent interactions and long duration Locally embedded
Regional culture	Opening, collaborative, and risk-taking	Close, hierarchical, and risk-avoiding
Public R&D resource allocation	Bottom-up, peer-reviewed, and curiosity-based mechanism	Top-down, mission-based, and performance-based mechanism
Performance	Long-term-oriented outputs (often innovation-oriented)	Immediate outputs (often economically oriented)

Source: partly extracted and developed from Gilsing and Nooteboom [71].

4. Operationalizing the exploration-exploitation approach: an application to the evolution of China's RISs between 1986-2011

In this section we discuss our methods and then explore the evolution of China's RIS in the 1986-2011 period. Chinese provinces are chosen as the unit of analysis and patents as proxies of the RIS technology base. We employ an entropy index as a measure of the extent of exploration-exploitation type activities in China's RISs, as well as clustering methods based around the calculated value of the province's entropy index to identify RIS patterns.

4.1. The Chinese case

China is a good example to demonstrate the application of an exploration-exploitation approach. China has emerged as the second largest economy in the world behind the United States and is undergoing a rapid transition in its economy and innovation systems, moving from the former centrally planned system to a market-driven one. On the one hand, this reconstruction process has stimulated local governments to develop their own technology facilities and suitable technology for local business demand. On the other, what were once centrally controlled innovation institutes, such as universities and research institutes, have to a large extent switched their innovation focus towards geographically co-localized demands for immediate returns [48]. Consequently, many scholars have observed that one prominent feature of this economy is the growing disparity in regional development levels in terms of innovation inputs and outputs [69, 47, 48]. Specifically, this is noticeable with regard to R&D, as measured by R&D expenditures and full-time equivalent (FTE) personnel (see Tables 3, 4). For example, in 2011, the five most innovative provinces accounted for half of the total R&D expenditures in China, and the top ten provinces accounted for 70%. Concerning the FTE personnel, the top five provinces accounted for 52% in 2011, and the top ten accounted for 73%.

Table 3: R&D expenditures by rank of province

Rank	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	0.11	0.10	0.11	0.10	0.13	0.13	0.11	0.12	0.12	0.12	0.14	0.14
2	0.18	0.19	0.20	0.20	0.22	0.22	0.21	0.22	0.22	0.24	0.26	0.26
3	0.26	0.27	0.28	0.28	0.30	0.31	0.30	0.32	0.32	0.33	0.35	0.35
4	0.33	0.34	0.35	0.36	0.36	0.37	0.37	0.39	0.40	0.41	0.42	0.43
5	0.40	0.39	0.41	0.41	0.42	0.43	0.44	0.46	0.48	0.48	0.50	0.50
10	0.65	0.64	0.67	0.66	0.66	0.66	0.66	0.68	0.69	0.69	0.69	0.70

Source: China Science & Technology Statistical Yearbooks: 2000-2011

Table 4: FTE personnel by rank of province

Rank	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	0.17	0.16	0.17	0.16	0.16	0.16	0.14	0.14	0.13	0.12	0.12	0.12
2	0.29	0.30	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24
3	0.38	0.38	0.38	0.38	0.38	0.37	0.36	0.36	0.35	0.35	0.35	0.35
4	0.46	0.47	0.47	0.46	0.46	0.45	0.45	0.45	0.45	0.44	0.45	0.45
5	0.52	0.53	0.53	0.52	0.54	0.53	0.53	0.53	0.53	0.51	0.52	0.52
10	0.74	0.76	0.76	0.76	0.76	0.76	0.75	0.75	0.74	0.73	0.73	0.73

Source: China Science & Technology Statistical Yearbooks: 2000-2011

In addition, from an output perspective, Figure 1 plots the cumulative proportion of patent applications against the rank of provinces ordered by the patent count in 2000 and 2011. It shows that the five most innovative provinces accounted for approximately 45% of the total patent applications in China in 2000. By 2011, this rose to 56%. The share of the top ten provinces increased from 69% to 76% in the same period. This highlights the coexistence of multiple-level RISs in China.

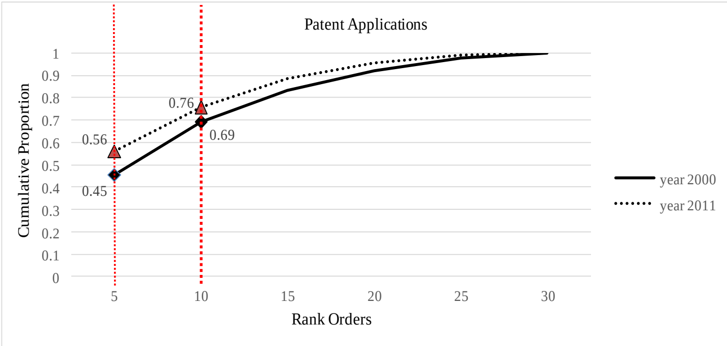


Figure 1: The cumulative proportion of patent applications

4.2 Methodology

We use Chinese provinces as the basic unit of RIS analysis, following a number of other studies [47, 54, 72]. Although using provinces is still controversial in the Chinese case, choosing the administrative provincial-level regions as our unit of analysis seems appropriate [1]. Li [48] notes, for example, that Chinese provinces are administratively and economically independent geographical regions. Since the open-door policy of 1978, each province has had its own government rules, technology and innovation policies, and different R&D expenditure budgets. Further, the dialect, customs, conventions, and cultures have both local and regional traits. In China's long history, each region has developed and evolved its own distinguished historical, cultural, and geographical features, which play important roles in driving local knowledge spillovers and the evolutionary processes of regional innovation.

Ultimately, although there is increasingly mobility of labor between Chinese provinces, people, particularly high-quality innovation personnel, often live and work in their registered permanent residence due to strict regulations (i.e., the so-called Hukou institution). Thus, tacit knowledge and historically developed social capital are powerfully bound to regions and can only be accessed within them.

Patent retrieval data have been widely used in innovation studies and have the potential for use in longitudinal and comparative studies [73-75]. Thus each province's patent applications registered with China's State of Intellectual Property Office (SIPO) between 1986 and 2011 are taken for our main entropy index measurement. Following some previous studies in the technological exploration-exploitation literature, we employ patents as proxies for a province's technology base. As discussed, explorative RISs typically evolve by widening their technology bases. In contrast, exploitative RISs evolve to have a narrower technological base and exhibit deepening activities of existing technologies. Based on this understanding, we employ the entropy index to measure exploration and exploitation. The entropy index is a popular method to measure centrality and dispersion [76, 77], specified as:

$$exploration-exploitation=\sum_{i=1}^{30} P_i \ln 1/P_i ,$$

where P_i is the ratio of the patents in technological classification i to the total patent applications in a province in an observed year. The calculated values are located between 0 and $\ln n$ (n is 30, the number of the technological patent classification). A higher value means that a province is likely to be an explorative RIS, while a lower value indicates the greater likelihood of a province belonging to an exploitative RIS.

In China, patents are categorized into three different types: inventions, utility models, and designs. Because the design type implies relatively lower technological advancement and is subject only to a simple application procedure without careful technological examination, we include only invention and utility model types in this study. In total, there were 3,705,975 patent applications during the 1986 to 2011 period. The original patent classes identified by the OECD can be grouped into 30 technological sectors, pooled together in technologically related patent classes (see Appendix I). Based on each province's entropy index, we utilize K-means, a commonly used method [78], to cluster provinces into three patterns: the explorative, exploitative and balanced RIS (which sits between the previous two types).

We embrace the interpretation of exploration-exploitation as a continuum and accordingly take a single operationalization (i.e., the entropy index) which is consistent with some prior studies [59, 79-81]. However, there are still other studies that conceptualize the two constructs, exploration and exploitation, as independent activities and thus utilize separate measurements [56, 82, 83]. As Stadler et al. [78] note, this conceptualization might underrate their interdependent nature, which lies at the heart of the question of how a balance can be obtained.

To capture the evolution process of Chinese RISs, we split our observations (1986-2011) into four periods.

- Phase I (1986-1992): pre-market-economy stage (marked by the open-door policy in 1978 and first patents in 1986 at SIPO)
- Phase II (1993-2001): rapid market-economy development stage (marked by Deng Xiaoping's south China tour)
- Phase III (2002-2006): market-economy perfecting stage (marked by China's entry into World Trade Organization (WTO))
- Phase IV (2007-2011): indigenous innovation development stage (marked by the issue of the *National Program for Medium- to Long-term Scientific and Technological Development* (2006-2020))

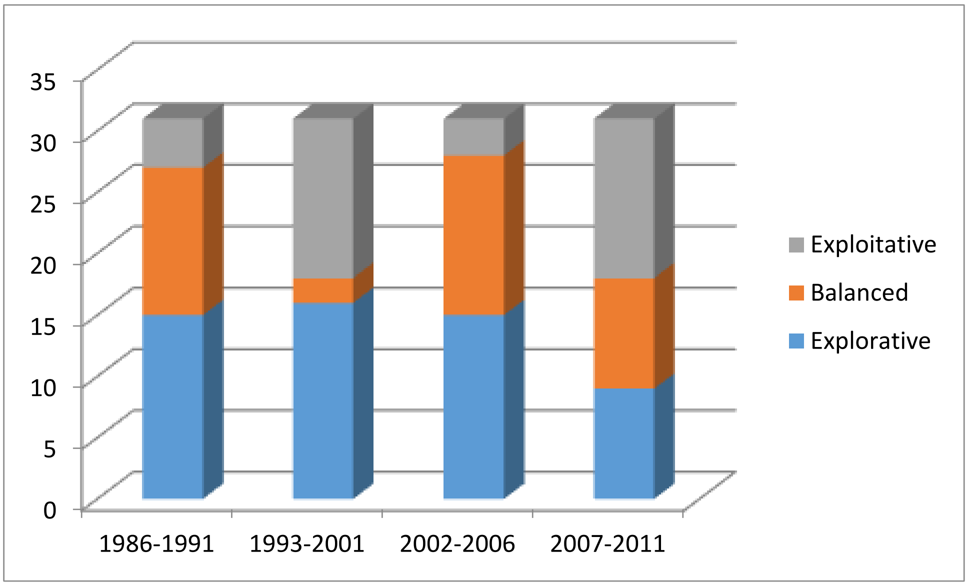
5. Results and discussion

Based on the entropy index and relevant clustering methods, we identify RIS patterns for all 31 Chinese provinces. Figures 2 and 3 provide insights into the aggregate trends for all 31 provinces. As noted, there is considerable interest and discussion of regional disparities in patenting across China's regions. Hence each province's entropy index and its change over time (in the four periods) are also presented in Tables 5, 6 and 7 and decomposed into eastern, western and central regions (where 0 denotes balanced, 1 explorative and -1 an exploitative RIS).

5.1 General trends in RISs from an exploration-exploitation perspective

We first report the general trends in RISs over the four periods (figures 2 and 3). Figure 2 shows that in the first period 12 provinces were categorized as balanced, 15 provinces explorative and four provinces exploitative RISs (Figure 2). These latter four predominantly belonged to economically and technologically lagging regions (Ningxia, Qinghai, Xizang and Hainan). In general they deepened their existing technology bases by focusing on a limited number of technological areas. For instance, from 1986 to 1992, Ningxia's patent applications were dominated by consumer goods and equipment, control and instrumentation technology and civil engineering, mining and architecture (accounting for 33.13% of all of its total patent applications). If these numbers extend to its top 10 areas, the ratio rises to 73.91%. Among the 15 provinces exhibiting explorative RIS patterns in this period there were differences in size. Beijing, for example, had a total number of 18,856 patents in its portfolio, and these were almost equally dispersed across all technological areas. Gansu, by contrast, only applied 1,540 patents. There were 12 provinces with balanced RISs, mostly located in China's inner regions.

Figure 2: Overall trends in explorative, balanced and exploitative RISs.



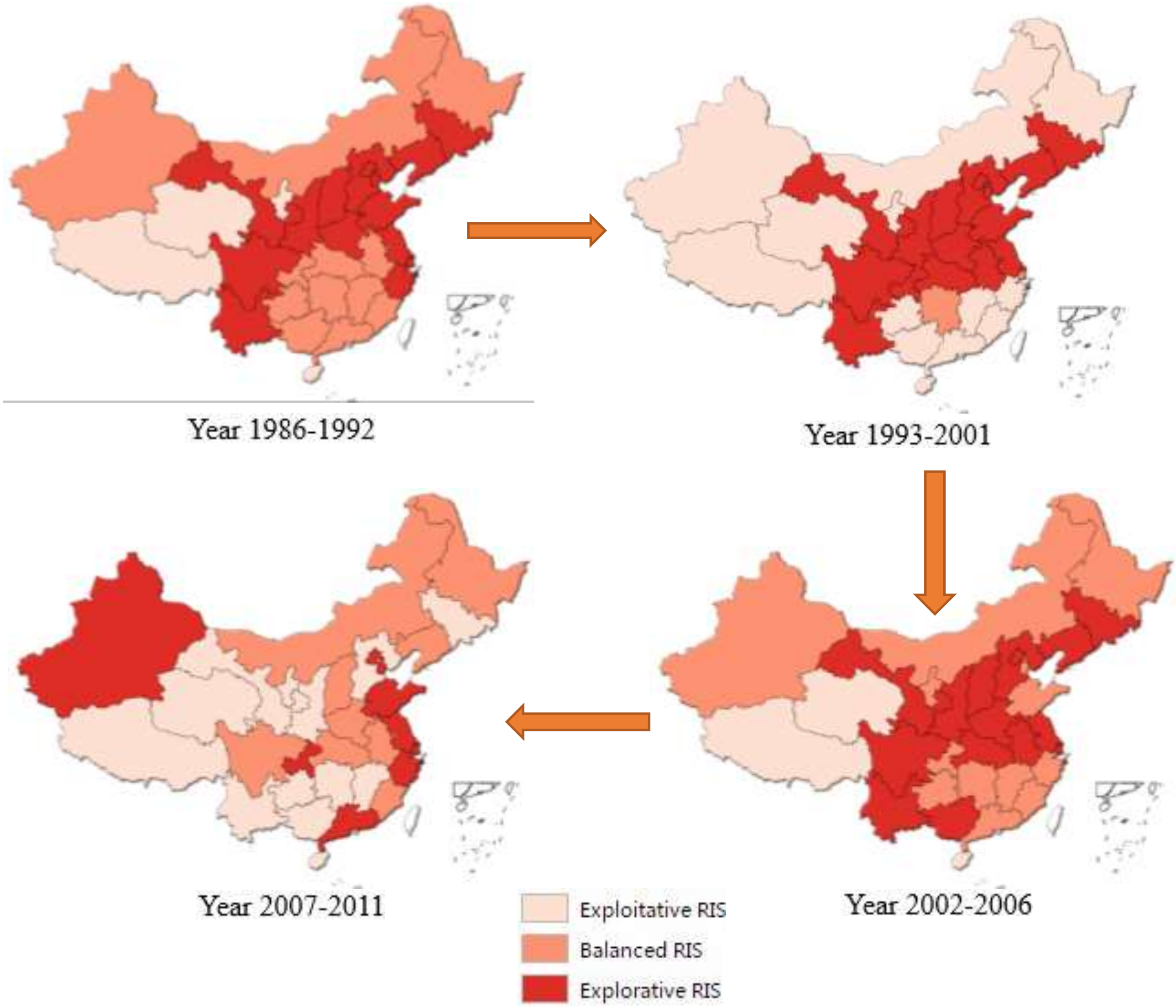
In the second period under study (rapid market economy development) regions gained further incentives to develop their local economies. Chinese RISs therefore experienced considerable development [34] and regions began to form more distinctive RISs (i.e. the number of balanced systems decreased). The prominent characteristic of this stage therefore is the gravitation of each province towards either an explorative or exploitative RIS. The number of balanced RISs fell to just two. The explorative RISs, moreover, were generally located in eastern China's relatively developed regions (e.g., Shandong, Jiangsu, and Tianjin) and some inner though relatively more developed regions (e.g., Shaanxi, Hubei and Sichuan). China's central and western regions predominately had exploitative RISs.

In the third period (encompassing China's entry into the WTO in 2001), regional and international competition intensified. This afforded regions further opportunities to learn from each other and stimulated greater inter-regional technological flows. One interpretation of trends in this stage is that many exploitative regions moved to tap into growing technological opportunities and thus widen the scope of their technology base. This shift is illustrated by a rise in balanced RISs from three to 13. Most explorative RISs maintained their orientation during this stage.

In the fourth stage (nine balanced, nine explorative and 13 exploitative RISs) provinces gravitated towards what may appear to be appropriate patterns given their overall level of economic development. Regions with a relatively high level of development (and thus having more resources to invest in explorative innovation) moved towards explorative systems, while resource constrained provinces were exploitative.

Figure 3 illustrates the evolution of Chinese RISs using color-coded maps for each of the four observed stages (A map of China is presented in Appendix II).

Figure 3 Mapping the evolution of Chinese RISs though four stages



5.2 Temporal variations in RISs by province

While figures 2 and 3 provide a general summary of patterns in China's RISs, to fully appreciate RIS trends it is necessary to undertake more fine grained analysis, one considering individual provincial trends. Relying solely on figures 2 it is impossible to identify the predominant RISs in each province over the period 1986-2011. To address this Tables 5,6, and 7 note each systems' category based on the predominance of RISs over the four periods. Within the eastern region of China, as might be expected, explorative RISs predominate (9 of 11 provinces, with 2 balanced and none exploitative, see Table 5). In the 9 central regions explorative RISs also dominated, though there was a further tendency towards balanced and exploitative systems (5 explorative, 3 balanced and 1 exploitative RIS). In the west, by contrast, exploitative systems were far more common (5 exploitative, 1 balanced, 5 explorative).

Relying solely on figures 2 and 3, moreover, might also suggest that considerable volatility in the overall RIS patterns exists within China. Looking at the further disaggregated results and undertaking analysis by province and period, however, actually suggests the opposite. Our interpretation of tables 5, 6 and 7 is that a degree of stability exists in the orientation of China's RISs (i.e. they had a clear and definite tendency towards either exploration or exploitation). Looking at the regional decomposition (tables 5,6,7), for example, we see that only nine of the 31 provinces made a step change jump between being either an explorative and exploitative system (or vice versa) during the period under study (i.e. exhibited both a 1 and -1 within the four periods of observation, i.e. between 1986 and 2011). These nine provinces included Zhejiang, Guangdong and Hebei in the east (Table 5), Jilin in central China (Table 6) and Shaanxi, Xinjiang, Guangxi, Gansu and Yunnan in the west (Table 7).

For the remaining 22, therefore, while there was at times movement between the balanced and either explorative or exploitative states, none of them underwent a step change reversal.

Building from this observation, it is interesting to consider the nine step change provinces in further detail. There are several points to note. Firstly, RISs more likely to make the step change (as indicated by both a 1 and -1 within the four periods of observation for any given province) tended to be more common in the western inland regions. Five of the 11 inland provinces, for example, (as compared to three of the 11 eastern provinces), underwent this reversal (and only one of nine in central regions). Building from the extant research on China's RISs, therefore, we can infer that inland provinces not only patent less than their coastal counterparts, they also tend to do so within relatively restricted classes of technology. This makes them more likely to be exploitative RISs.

Secondly, of the nine provinces experiencing system step changes, the general tendency was towards an exploitative system when looking from the perspective of the outcome in the final observation period (i.e. a -1 was recorded in the final period of observation in 2011). Thus six of the nine provinces that experienced step change volatility were recorded as exploitative systems in the final observation period. One possible interpretation of this evidence could be that moving towards a categorization as an exploratory system for a sustained period was in general difficult to achieve. In other words, although some provinces could temporarily make the jump, comparatively fewer could maintain their positions as explorative RISs. Further looking at these six provinces, however, it is also striking that for five of them considerable stability had been experienced in all of the preceding three periods prior to the step change (i.e. between 1986 and 2006). Thus Yunnan, Gansu, Guangxi, Shaanxi, Jilin and Hebei, for example, had all been categorized as explorative regions for the entirety of the three periods prior to 2007-2011. This raises the question of why some seemingly stable exploratory RISs made the sudden step change transitions towards exploitative systems in the final period under study. One possible explanation, certainly applicable for the less prosperous western regions, might be related to the aforementioned growth in businesses (i.e. as opposed to universities and research institutes) as drivers of Chinese regional innovation. As businesses become relatively more important drivers of innovation (and universities and research institutes less so) so too does the tendency towards exploitative categorization increase. This is because their innovation activities are more concentrated in certain industries in the more inland, western regions. Clearly, this question regarding the rapid transformation of apparently stable systems warrants further investigation and it is an interesting observation we draw from our use of the current exploration-exploitation approach.

Table 5: RIS patterns in East China, 1986 to 2011

Province	1986-1991	1993-2001	2002-2006	2007-2011	Predominance 1986-2011	Step change
Tianjin	1	1	0	1	Explorative	No
Shanghai	1	0	1	1	Explorative	No
Beijing	1	1	1	1	Explorative	No
Jiangsu	1	1	1	1	Explorative	No
Zhejiang	1	-1	0	1	Explorative	Yes
Guangdong	0	-1	0	1	Balanced	Yes
Liaoning	1	1	1	0	Explorative	No
Fujian	0	-1	0	0	Balanced	No
Shandong	1	1	0	1	Explorative	No
Hebei	1	1	1	-1	Explorative	Yes
Hainan	-1	-1	-1	-1	Exploitative	No

Notes: 'step change' refers to whether the province experienced both an explorative or exploitative categorization of at least once during the 1986-2011 period. The predominance column is based on the frequency of RIS over the four periods. We have rounded up and down the entropy indexes (to -1 and 1).

Table 6: RIS patterns in central China, 1986 to 2011

Province	1986-1991	1993-2001	2002-2006	2007-2011	Predominance 1986-2011	Step change
Neimenggu	0	-1	0	0	Balanced	No
Jilin	1	1	1	-1	Explorative	Yes
Hubei	0	1	1	0	Explorative	No
Heilongjiang	0	-1	0	0	Balanced	No
Shanxi	1	1	1	0	Explorative	No
Hunan	0	0	0	-1	Balanced	No
Henan	1	1	1	0	Explorative	No
Jiangxi	0	-1	0	-1	Exploitative	No
Anhui	0	1	1	0	Explorative	No

Table 7: RIS patterns in west China, 1986-2011

Province	1986-1991	1993-2001	2002-2006	2007-2011	Predominance 1986-2011	Step change
Chongqing	0	1	0	1	Explorative	No
Ningxia	-1	-1	0	-1	Exploitative	No
Shaanxi	1	1	1	-1	Explorative	Yes
Xizang	-1	-1	-1	-1	Exploitative	No
Xinjiang	0	-1	0	1	Balanced	Yes
Sichuan	1	1	1	0	Explorative	No
Guangxi	0	-1	1	-1	Exploitative	Yes
Guizhou	0	-1	0	-1	Exploitative	No
Gansu	1	1	1	-1	Explorative	Yes
Yunnan	1	1	1	-1	Explorative	Yes
Qinghai	-1	-1	-1	-1	Exploitative	No

The sudden reversal of these five provinces (Yunnan, Gansu, Shaanxi, Jilin and Hebei) is also of interest from a policy-making perspective. It is suggested that explorative RISs tend to be oriented towards long-term innovation and economic outputs resulting from leading and advanced technologies. In exploitative RISs, by contrast, immediate outputs are sought using existing technologies and capabilities. The observed shift from explorative to exploitative systems in these cases may not augur well for China as it looks to move beyond middle income levels by relying on productivity spurring innovation. This is currently a major policy concern in China, as it looks to navigate its way through the middle income trap.

As well as the above five cases, there are several other exceptional cases that appear to exhibit some volatility in their RISs. Guangdong and Xinjiang, for example, have both fluctuated between balanced, exploitative, balanced and then explorative RISs.

In each of these cases, however, the progression between any one period has not involved a step change. Clearly further research is required to establish exactly what lies beneath the evolution of these RISs. The cases of Guangxi and Zhejiang also warrant further explanation, as while a predominant RIS can be identified (exploitative in the former case, explorative in the latter), considerable volatility appears to exist in the evolution of their RISs.

5.3. Impact of institutions and policy-making on RIS orientation

As already discussed, Li has convincingly identified provincial level subsidization policies as a vital stimulus to the upsurge in patenting activity in the post 2001 period (of all types of patents, i.e. non industry specific) [48]. Such policies greatly lowered the cost of making patent applications for businesses and individuals alike. As a result, Li has shown how those provinces that were the first and most aggressive at introducing such policies saw a considerable upturn in their patent approvals (controlling for other possible influences). The most proactive provinces included: Shanghai, Guangdong, Beijing, Tianjin, Jiangsu and Chongqing. These provinces were the first to introduce subsidies (around 200 and 2001). Interestingly, our results show that they had all developed strong exploratory orientations in their RISs by the final period of observation (Table 5). From a policy perspective, therefore, it is relevant to note that 6 of the 9 provinces that were classified as exploratory in the final period of observation were also those that were among the earliest to introduce subsidies for patent applications, suggesting such policies not only had an impact on patenting volumes, but also did so across a wide range of technological classes and helped foster explorative type RISs.

6. Conclusion

Owing to China's regional differences, in terms of government support, composition, and the capabilities of the R&D actors and the industry-specific environment, innovation performances and paths of innovation system development vary widely [47]. This paper employs an alternative and novel exploration-exploitation framework and applies it to understanding the evolution of China's RISs. Traditional RIS approaches (i.e., the structural, functional, effectiveness and the triple helix approaches) have dominated study China's RIS. While they have their advantages and drawbacks (i.e. their static and excessively theoretical nature, sometimes lacking comparative longitudinal empirical analyses) the focus of existing RIS research has often looked to explain patenting volumes and the associated regional disparities. Comparatively little interest has been shown, however, in the evolution of the variation in the technological fields of these patents (i.e. an aspect of their qualitative nature) and the related evolution of the exploratory or exploitative orientation of these systems. Encouraged by other somewhat similar research [1, 69, 70], we categorized China's RISs into two areas, namely knowledge generation and knowledge application systems and used the entropy index to categorize explorative and exploitative systems. The approach we adopt sheds more light on the diversity of

Chinese patenting activity across technological fields. This, in turn, also has important links to the overall nature of China's RISs, which helps enrich our understanding of them. Thus extending the exploration-exploitation approach from the dominant organizational level to the regional level provides different perspectives on the evolution of China's RISs.

Specifically, we found that while a degree of persistence may exist in RIS orientation in 22 of China's provinces (with wealthier more developed regions generally exhibiting explorative tendencies and less step-change volatility), in another nine provinces significant step change shifts did occur. These, moreover, were often not always positive step changes, being associated with comparatively long periods of an explorative orientation punctuated by a sudden movement towards exploitative systems, particularly in the final (2007-2011) period of observation. As China looks to develop more advanced explorative innovation systems so as to escape the middle income trap by fostering productivity led growth, this pattern arguably does not augur particularly well. We also found some evidence for the view, however, that institutional arrangements (particularly government subsidization of patent applications) may facilitate explorative RISs in China and that there may therefore be some credible policy options available. In general, moreover, our findings support the view that not only are disparities in patenting activities widening between provinces in China but also that considerable gaps in the qualitative nature of patenting activity (i.e. in terms of its span of technological classes) also exist.

6. 1. Limitations

We recognize there are a number of potential limitations in our study and note possible directions for future research that may address these. Firstly, we use provinces as our unit of analysis, following quite a number of other studies on China's RISs that also do so. It may be argued this is an inappropriate unit of analysis and more refined approaches should be developed. Further research could look to ascertain how altering the unit of analysis feeds back into our understanding of China's RISs. Secondly, we also use invention and utility patents and exclude design patents as our measure of exploration and imitation. We thus follow Li's (2009) approach. He argues that utility patents represent a middle level of patenting activity and that the ease with which design patents are secured does not make them a good indicator of innovative activity (even of an exploitative nature). Further research could investigate how the use of different patent classes affects these results. Finally, at the organization level the entropy index is usually calculated from the proportional distribution of patents across patent classes. It may be questioned whether this is an ideal measure of exploration or exploitation at the regional level, especially given the difference of natural resource endowments (or prior industrial bases) across regions. Since not every industry (or technological field) exists in every region, the entropy index may represent the established industrial structure (or technology base) of an RIS. As such, care must be used when interpreting results using the entropy index at the regional level and in turn drawing conclusions regarding the specific nature of the innovation being undertaken.

References

[1] F. Tödtling, M. Trippl, One size fits all? Towards a differentiated regional innovation policy approach, Res. Policy 34 (8) (2005) 1203-1219.

[2] C. Freeman, The National Innovation Systems in historical perspective, Cambr. J. Econ. 19 (1) (1995).

[3] Edquist, Systems of Innovation: Technologies, Institutions and Organizations, in, Pinter Publishers, London, 1997.

[4] B.-Å. Lundvall, National systems of production, innovation and competence building, Res. Policy 31 (2) (2002) 213-231.

[5] B. Carlsson, On and off the beaten path: The evolution of four technological systems in Sweden, Int. J. Ind. Organ. 15 (6) (1997) 775-799.

[6] S. Breschi, F. MaLerba, Sectoral Innovation Systems, in: Edquist (Ed.) Systems of Innovation: Technologies, Institutions and Organizations, Pinter Publishers, London, 1997, pp. 41-63.

[7] Z. Acs, Regional Innovation: Knowledge and Global Change, Pinter, London, 2000.

[8] B. Carlsson, S. Jacobsson, M. Holmén, A. Rickne, Innovation systems: analytical and methodological issues, Res. Policy 31 (2) (2002) 233-245.

[9] J.R.L. Howells, Tacit Knowledge, Innovation and Economic Geography, Urban Stud. 39 (5/6) (2002) 871-884.

[10] A.Jaffe, M. Trajtenberg, M. Fogarty, Knowledge spillovers and patent ciations: Evidence from a survey of inventors, Am. Econ. Rev. 90 (2) (2004) 215-218.

[11] P. Cooke, M. Gomez Uranga, G. Etxebarria, RISs: Institutional and organisational dimensions, Res. Policy 26 (4-5) (1997) 475-491.

[12] D.B. Audretsch, M.P. Feldman, R&D Spillovers and the Geography of Innovation and Production, Am. Econ. Rev. 86 (3) (1996) 630-640.

[13] Y. Aoyama, Entrepreneurship and Regional Culture: The Case of Hamamatsu and Kyoto, Japan, Reg Stud. 43 (3) (2009) 495-512.

[14] Y.C. Chang, Systems of Innovation, Spatial Knowledge Links and the Firm's Innovation Performance: Towards a National-Global Complementarity View, Reg Stud. 43 (9) (2009) 1199-1223.

[15] Y. Cai, C. Liu, The roles of universities in fostering knowledge-intensive clusters in Chinese RISs, Sci. Public Policy (2014) doi: 10.1093/scipol/scu018.

[16] I.H. Lee, E. Hong, L. Sun, Regional knowledge production and entrepreneurial firm creation: Spatial Dynamic Analyses, J. Bus. Res. 66 (10) (2013) 2106-2115.

[17] J.L. Solleiro, C. Gaona, Promotion of a RIS: The Case of the State of Mexico, Procedia- Soc. Beha. Sci. 52 (2012) 110-119.

[18] S. Tiffin, M. Kunc, Measuring the roles universities play in RISs: a comparative study between Chilean and Canadian natural resource-based regions, Sci. Public Policy 38 (1) (2011) 55-66.

[19] B.-Å. Lundvall, Dynamics of Industruy and Innovation: Organizations, Networks and Systems, in: The DRUID Tenth Anniversary Summer Conference, Copenhagen,Denmark, 2005.

[20] R. Cowan, N. Zinovyeva, University effects on regional innovation, Res. Policy 42 (3) (2013) 788-800.

[21] R. Boschma, D. Fornahl, Cluster Evolution and a Roadmap for Future Research, Reg Stud. 45 (10) (2011) 1295-1298.

[22] D. Doloreux, S. Parto, RISs: Current discourse and unresolved issues, Technol. in Soc. 27 (2) (2005) 133-153.
[23] Y. Wang, W. Vanhaverbeke, N. Roijakkers, Exploring the impact of open innovation on national systems of innovation — A theoretical analysis, Technol. Forecast. Soc. Change 79 (3) (2012) 419-428.
[24] Y. Wang, Z. Zhou, Building an integrative framework for national systems of innovation, J. Knowl. based Innovation in China 3 (3) (2011) 160-171.
[25] C. Binz, B. Truffer, L. Coenen, Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology, Res. Policy 43 (1) (2014) 138-155.
[26] B.T. Asheim, L. Coenen, Knowledge bases and RISs: Comparing Nordic clusters, Res. Policy 34 (8) (2005) 1173-1190.
[27] C. Freeman, Technology, Policy, and Economic Performance: Lessons from Japan, Pinter Publishers, London, New York, 1987.
[28] B.-Å. Lundvall, National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter Publishers, London, New York, 1992.
[29] B.T. Asheim, H.L. Smith, C. Oughton, RISs: Theory, Empirics and Policy, Reg Stud. 45 (7) (2011) 875-891.
[30] A.Bergek, S. Jacobsson, B. Carlsson, S. Lindmark, A. Rickne, Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Res. Policy 37 (3) (2008) 407-429.
[31] M.P. Hekkert, S.O. Negro, Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims, Technol. Forecast. Soc. Change 76 (4) (2009) 584-594.
[32] A. Johnson, Functions in Innovation System Approaches, Electronic Paper at the Proceedings of the Nelson and Winter Conference Volume, 2001.
[33] B.-Å. Lundvall, Innovation as an interactive process: From user-producer interaction to the national system of innovation, in: G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg, L. Soete (Eds.) Technical Change and Economic Theory, Pinter Publishers, London, 1988, pp. 349-369.
[34] X. Liu, S. White, Comparing innovation systems: A framework and application to China's transitional context, Res. Policy 30 (7) (2001) 1091-1114.
[35] D.J. Teece, Competition, cooperation, and innovation: Organizational arrangements for regimes of rapid technological progress, J. Econ. Behav. Organ. 18 (1) (1992) 1-25.
[36] W. Leontief, The Structure of American Economy, 1919-1929. An Empirical Application of Equilibrium Anlaysis, Harvard University Press, Cambridge, MA, 1941.
[37] J. Guan, K. Zuo, A cross-country comparison of innovation efficiency, Scientometrics (2014) 1-35.
[38] J. Niosi, National systems of innovations are "x-efficient" (and x-effective): Why some are slow learners, Res. Policy 31 (2) (2002) 291-302.
[39] D. Lee, I. Seo, H. Choe, H. Kim, Collaboration network patterns and research performance: the case of Korean public research institutions, Scientometrics 91 (3) (2012) 925-942.
[40] K. Smith, Innovation as a Systemic Phenomenon: Rethinking the Role of Policy, Enterp. Innovation Mana. Stud. 1 (1) (2000) 73-102.
[41] C. Edquist, L. Hommen, Systems of innovation: theory and policy for the demand side, Technol. in Soc. 21 (1) (1999) 63-79.
[42] L. Leydesdorff, H. Etzkowtz, The triple helix as a model for innovation studies, Sci. Public Policy

25 (1998) 195-203.
[43] E.G. Carayannis, Knowledge transfer through technological hyperlearning in five industries, Technovation 19 (3) (1999) 141-161.
[44] H. Etzkowitz, C. Zhou, Triple helix twins: Innovation and sustainability, Sci. Public Policy 33 (2006) 77-83.
[45] H. Etzkowitz, L. Leydesdorff, The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university-industry-government relations, Res. Policy 29 (2) (2000) 109-123.
[46] K. Chen, J. Guan, The Chinese innovation system during economic of China's regional innovation systems: A structural approach, China Econ. Rev, 22 (2011) 11-27.
[47] X. Gao, X. Guo, K.J. Sylvan, J. Guan, The Chinese innovation system during economic transition: A scale-independent view, J.Informetr., 4 (2010) 618-628.
[48] X. Li, China's regional innovation capacity in transition: An empirical approach, Res. Policy, 38 (2009) 338-357.
[49] X. Li, Behind the recent surge of Chinese patenting: An institutional view, Res. Policy, 41 (2012) 236-249.
[50] Y. Sun, F. Liu, A regional perspective on the structural transformation of China's national innovation system since 1999, Technol. Forecast. Soc. Change, 77 (2010) 1311-1321.
[51] C.-H. Yang, H.-L. Lin, Openness, absorptive capacity, and regional innovation in China, Env. Plan.A, 44 (2012) 333.
[52] D. Sutherland, China's science parks: production bases or a tool for institutional reform?, Asia Pacific Bus. Rev., 11 (2005) 83-104.
[53] J.-H. Eun, K. Lee, G. Wu, Explaining the “University-run enterprises” in China: A theoretical framework for university–industry relationship in developing countries and its application to China, Res. Policy 35 (9) (2006) 1329-1346.
[54] K. Chen, M. Kenney, Universities/research institutes and RISs: The cases of Beijing and Shenzhen, World Dev. 35 (6) (2007) 1056-1074.
[55] J.G. March, Exploration and exploitation in organizational learning, Org. Sci. 2 (1) (1991) 71-87.
[56] Z.-L. He, P.-K. Wong, Exploration vs. Exploitation: An Empirical Test of the Ambidexterity Hypothesis, Org. Sci. 15 (4) (2004) 481-494.
[57] A.K. Gupta, K.G. Smith, C.E. Shalley, The interplay between exploration and exploitation, Acad. Manage. J. 49 (4) (2006) 693-706.
[58] S. Raisch, J. Birkinshaw, G. Probst, M.L. Tushman, Organizational Ambidexterity: Balancing Exploitation and Exploration for Sustained Performance, Org. Sci. 20 (4) (2009) 685-695.
[59] C. Stadler, T. Rajwani, F. Karaba, Solutions to the Exploration/Exploitation Dilemma: Networks as a New Level of Analysis, Int. J. Manag. Rev. 16 (2) (2013) 172-193.
[60] D. Leonard-Barton, Core capabilities and core rigidities: A paradox in managing new product development, Strateg. Manage. J. 13 (1992) 111-126.
[61] D. Lavie, L. Rosenkopf, Balancing exploration and exploitation in alliance formation, Acad. Manage. J. 49 (4) (2006) 797-818.
[62] C. Fang, J. Lee, M.A. Schilling, Balancing Exploration and Exploitation Through Structural Design: The Isolation of Subgroups and Organizational Learning, Org. Sci. 21 (3) (2010) 625-642.
[63] T.J. Mom, F.A. Van Den Bosch, H.W. Volberda, Investigating managers' exploration and exploitation activities: The influence of top-down, bottom-up, and horizontal knowledge inflows, J. Manage. Stud. 44 (6) (2007) 910-931.

[64] M. Hernández-Espallardo, M. Sánchez-Pérez, C. Segovia-López, Exploitation- and exploration-based innovations: The role of knowledge in inter-firm relationships with distributors, Technovation 31 (6) (2011) 203-215.
[65] H. Hoang, F.T. Rothaermel, Leveraging internal and external experience: exploration, exploitation, and R&D project performance, Strateg. Manage. J. 31 (7) (2010) 734-758.
[66] J. Hoppmann, M. Peters, M. Schneider, V.H. Hoffmann, The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry, Res. Policy 42 (4) (2013) 989-1003.
[67] S. Bonesso, F. Gerli, A. Scapolan, The individual side of ambidexterity: Do individuals' perceptions match actual behaviors in reconciling the exploration and exploitation trade-off?, Eur. Manage. J. 32 (3) (2014) 392-405.
[68] E. Autio, Evaluation of RTD in regional systems of innovation, Eur. Plan. Stud. 6 (2) (1998) 131-140.
[69] M.-C. Liu, S.-H. Chen, MNCs' offshore R&D networks in host country's RIS: The case of Taiwan-based firms in China, Res. Policy 41 (6) (2012) 1107-1120.
[70] Y. Wang, J. Li-Ying, When does inward technology licensing facilitate firms' NPD performance? A contingency perspective, Technovation 34 (1) (2014) 44-53.
[71] V. Gilsing, B. Nooteboom, Exploration and exploitation in innovation systems: The case of pharmaceutical biotechnology, Res. Policy 35 (1) (2006) 1-23.
[72] X. Fu, Foreign Direct Investment, Absorptive Capacity and Regional Innovation Capabilities: Evidence from China, Oxfs. Dev. Stud. 36 (1) (2008) 89-110.
[73] D. Archibugi, M. Planta, Measuring technological change through patents and innovation surveys, Technovation 16 (9) (1996) 451-468.
[74] J. Hagedoorn, M. Cloodt, Measuring innovative performance: is there an advantage in using multiple indicators?, Res. Policy 32 (8) (2003) 1365-1379.
[75] B.H. Hall, A. Jaffe, M. Trajtenberg, The NBER patent citations data file: Lessons, insights, and methodological tools, in: Jaffe, Trajtenberg (Eds.) Patents, Citations, and Innovations, The MIT Press, Cambridge, MA, 2001.
[76] S.P. Raghunathan, A refinement of the entropy measure of firm diversification: Toward definitional and computational accuracy, J. Manag. 21 (5) (1995) 989-1002.
[77] Y.-C. Chiu, H.-C. Lai, T.-Y. Lee, Y.-C. Liaw, Technological diversification, complementary assets, and performance, Technol. Forecast. Soc. Change 75 (6) (2008) 875-892.
[78] G. Krishnasamy, A.J. Kulkarni, R. Paramesran, A hybrid approach for data clustering based on modified cohort intelligence and K-means, Expert Syst. Appl. 41 (13) (2014) 6009-6016.
[79] K. Laursen, M.I. Leone, S. Torrisi, Technological exploration through licensing: New insights from the licensee's point of view, Ind. Corp. Change 19 (3) (2010) 871-897.
[80] D. Lavie, J. Kang, L. Rosenkopf, Balance within and across domains: The performance implications of exploration and exploitation in alliances, Org. Sci. 22 (6) (2011) 1517-1538.\
[81] A. Phene, S. Tallman, P. Almeida, When do acquisitions facilitate technological exploration and exploitation?, J. Manag. 38 (3) (2012) 753-783.
[82] J.J.P. Jansen, F.A.J.V.D. Bosch, H.W. Volberda, Exploratory Innovation, Exploitative Innovation, and Performance: Effects of Organizational Antecedents and Environmental Moderators, Manage. Sci. 52 (11) (2006) 1661-1674.
R. Katila, G. Ahuja, Something old, something new: A longitudinal study of search behavior and new

product introduction, Acad. Manage. J. 45 (6) (2002) 1183-1194.

Appendix I: Technological categorization and relevant patent classification

Technological Field	Patent Classification
Electrical Devices and Engineering	F21,G05F,H01B,H01C,H01F,H01G,H01H,H01J,H01K,H01M,H01R,H01T, H02,H05B,H05C,H05F,H05K
Audio-visual Technology	G09F,G09G,G11B,H03F,H03G,H03J,H04N,H04R,H04S
Communication	G08C,H01P,H01Q,H03B,H03C,H03D,H03H,H03K,H03L,H03M,H04B, H04H,H04J,H04K,H04L,H04M,H04Q
Information Technology	G06,G10L,G11C
Semiconductor	B81,H01L
Optics	G02,G03,H01S
Control and Instrumentation Technology	G01B,G01C,G01D,G01F,G01G,G01H,G01J,G01K,G01L,G01M,G01N, G01P,G01R,G01S,G01V,G01W,G04,G05B,G05D,G07,G08B,G08G,G09B, G09C,G09D,G12
Medical Technology	A61B,A61C,A61D,A61F,A61G,A61H,A61J,A61L,A61M,A61N
Nuclear Engineering	G01T,G21,H05G,H05H
Fine Organic Chemistry	C07C,C07D,C07F,C07G,C07H,C07J
Polymer Chemistry	C08B, C08F,C08G,C08H,C08K,C08L,C09D,C09J
Chemical Engineering	B01,B02C,B03,B04,B05B,B06,B07,B08,F25J,F26B
Surface Processing, Coating	B05C,B05D,B32,C23,C25,C30
Material, Metallurgy	B22,B82,C01,C03C,C04,C21,C22
Biotechnology	C07K,C12M,C12N,C12P,C12Q,C12S
Pharmaceuticals, Cosmetics	A61K,A61P
Agriculture, Food	A01H,A21D,A23B,A23C,A23D,A23F,A23G,A23J,A23K,A23L,C12C,C12F,C12G, C12H,C12J,C13D,C13F,C13J,C13K
Petroleum Industry and Material Chemistry	A01N,C05,C07B,C08C,C09B,C09C,C09F,C09G,C09H,C09K,C10,C11
Hauling and Printing	B25J,B41,B65,B66,B67B,B67C,B67D
Food Processing, Machinery and Equipment	A01B,A01C,A01D,A01F,A01G,A01J,A01K,A01L,A01M,A21B,A21C,A22, A23N,A23P,B02B,C12L,C13C,C13G,C13H
Material Processing, Textile, Papermaking	A41H,A43D,A46D,B28,B29,B31,C03B,C08J,C14,D01,D02,D03,D04B, D04C,D04G,D04H,D05,D06(except F、N),D21
Environmental Technology	A62D,B09,C02,F01N,F23G,F23J
Machine Tool	B21,B23,B24,B26D,B26F,B27,B30
Engine, Pump, Turbine	F01B,F01C,F01D,F01K,F01L,F01M,F01P,F02,F03,F04,F23R
Heat Treatment and Equipment	F22,F23B,F23C,F23D,F23H,F23K,F23L,F23M,F23N,F23Q,F24,F25B, F25C,F27,F28
Mechanical Components	F15,F16,F17,G05G
Transportation	B60,B61,B62,B63B,B63C,B63H,B63J,B64B,B64C,B64D,B64F
Space Technology and Weapon	B63G,B64G,C06,F41,F42
Consumer Goods and Equipment	A24,A41B,A41C,A41D,A41F,A41G,A42,A43B,A43C,A44,A45,A46B, A47,A62,A63,B25B,B25C,B25D,B25F,B25G,B25H,B26B,B42,B43, B44,B68,D04D,D06F,D06N,D07,F25D,G10B,G10C,G10D,G10F,G10G,

	G10H,G10K
Civil Engineering, Mining, Architecture	E01,E02,E03,E04,E05,E06,E21

Appendix II Map of China's Provinces